Optical and NIR observations for gravitational-wave counterpart by J-GEM collaboration

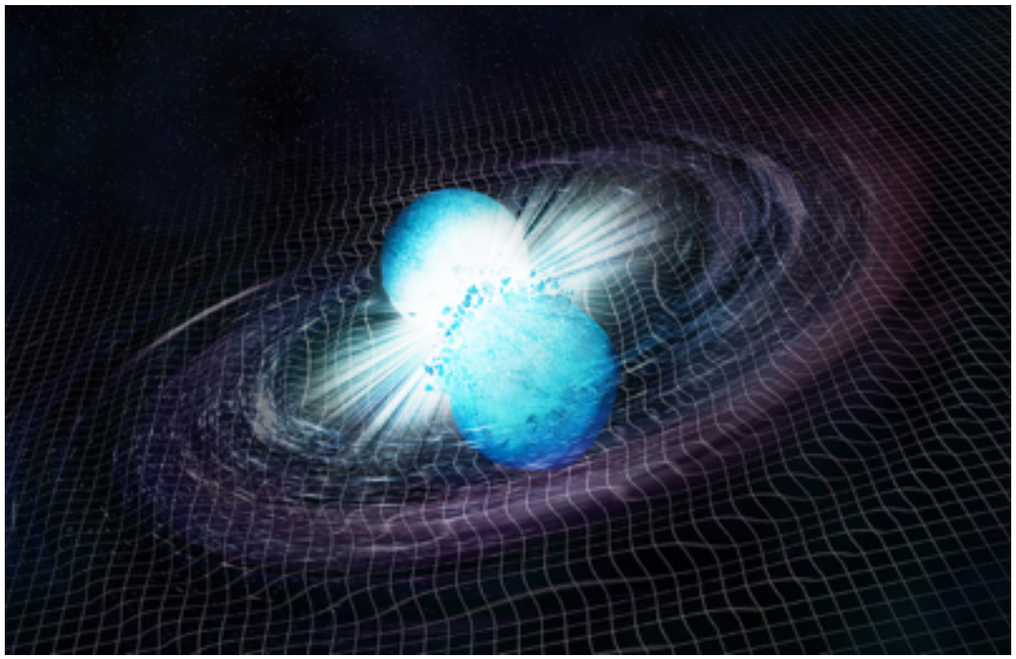
Mahito Sasada (Hiroshima University)
on behalf of J-GEM Team

Electro-magnetic counterpart for GW phenomenon

Electro-magnetic (EM) counterpart

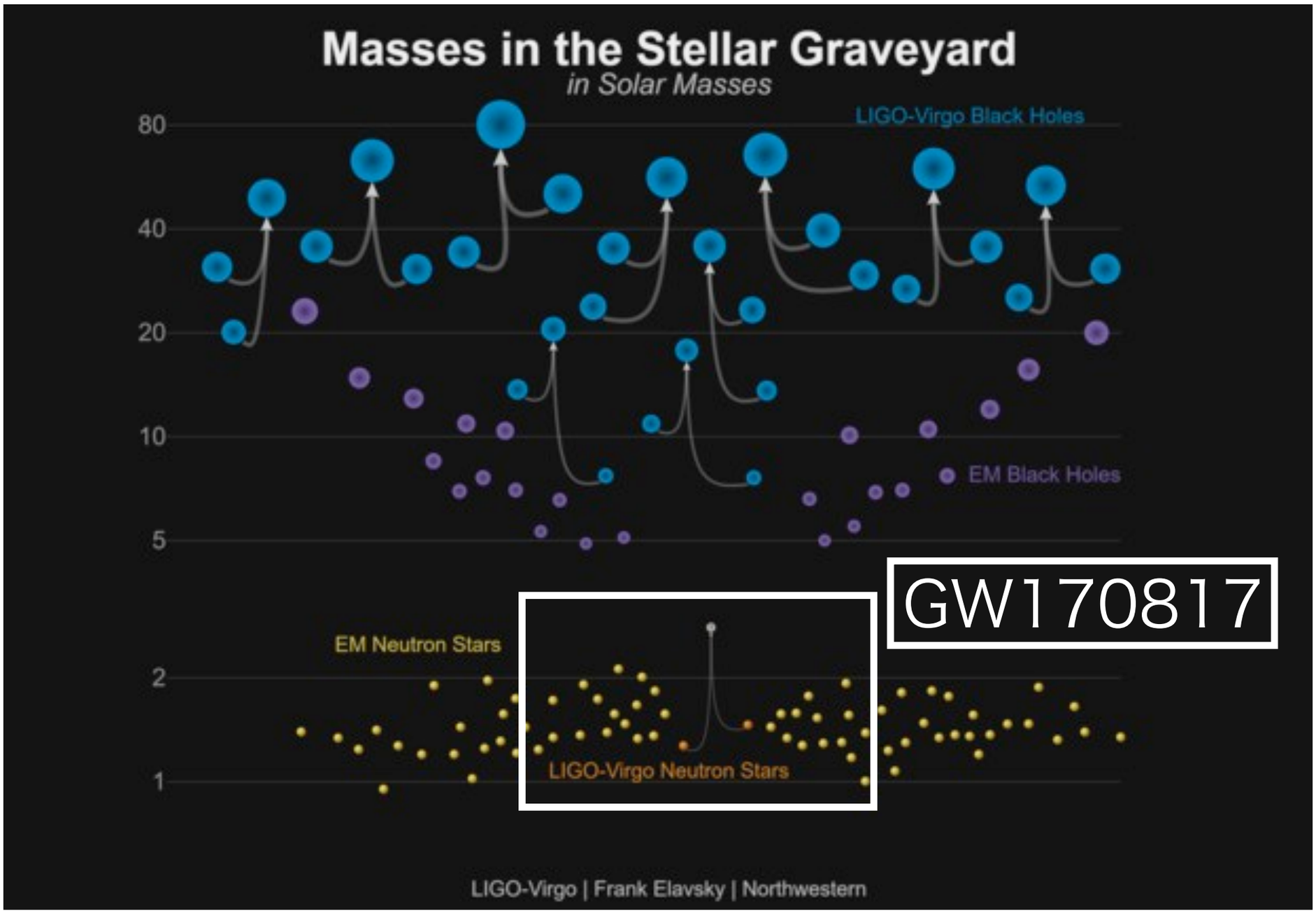
- Mergers of black hole-neutron star (BH-NS), and binary neutron star (BNS) pairs are expected to radiate an EM emission.

NASA/CXC/M.Weiss



- The EM data of GW source tell us different aspects of the merger event.
- Multi-messenger observation can reveal the physical background of the merger.

GW sources discovered by LIGO/Virgo



Credits: LIGO/Virgo/Northwestern Univ./Frank Elavsky

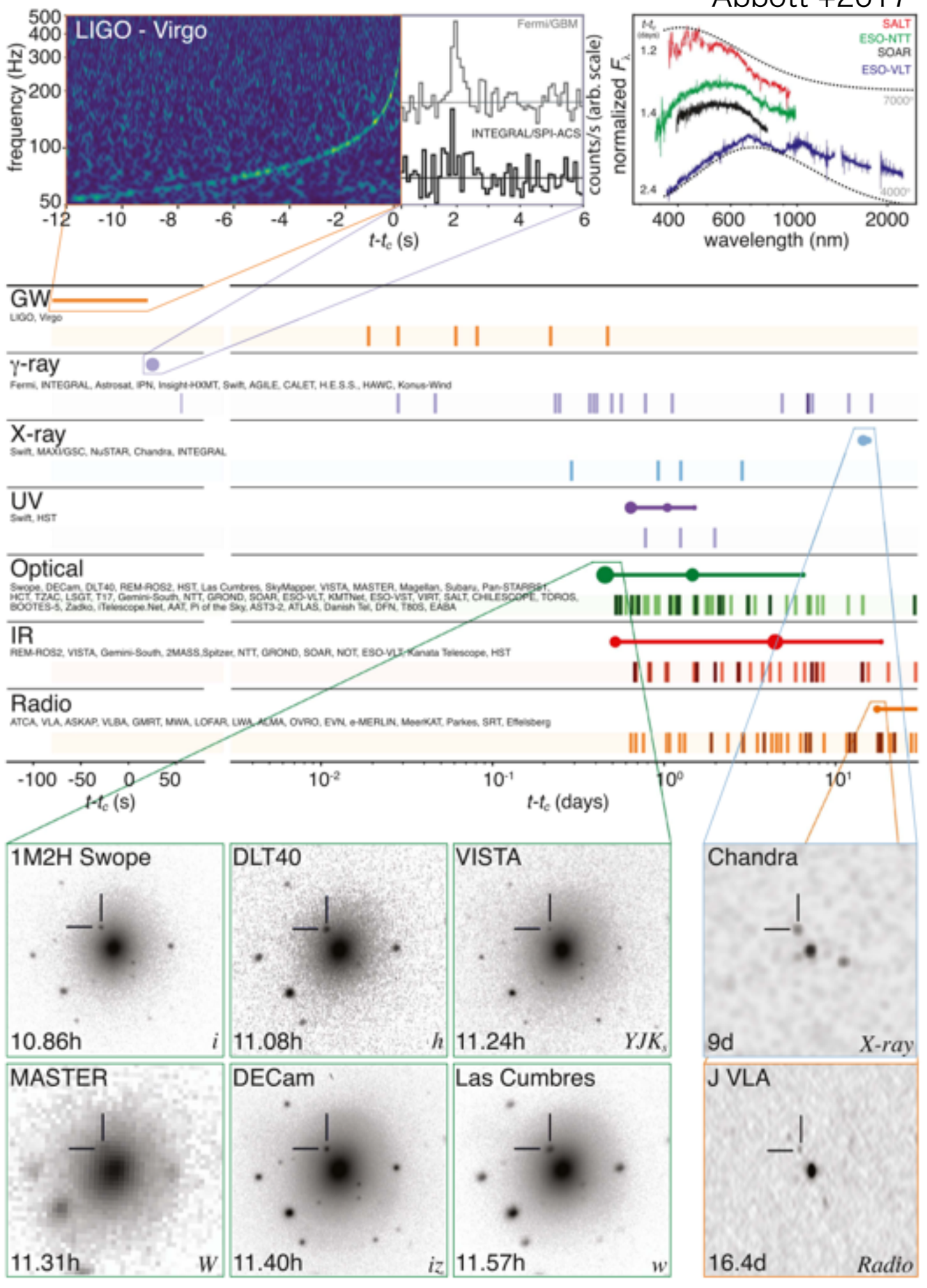
The EM Observations for GW170817

GW170817

- LIGO/Virgo detected the GW on 17 Aug. 2017.
- GW170817 was identified as the EM counterpart in the entire wavelength.

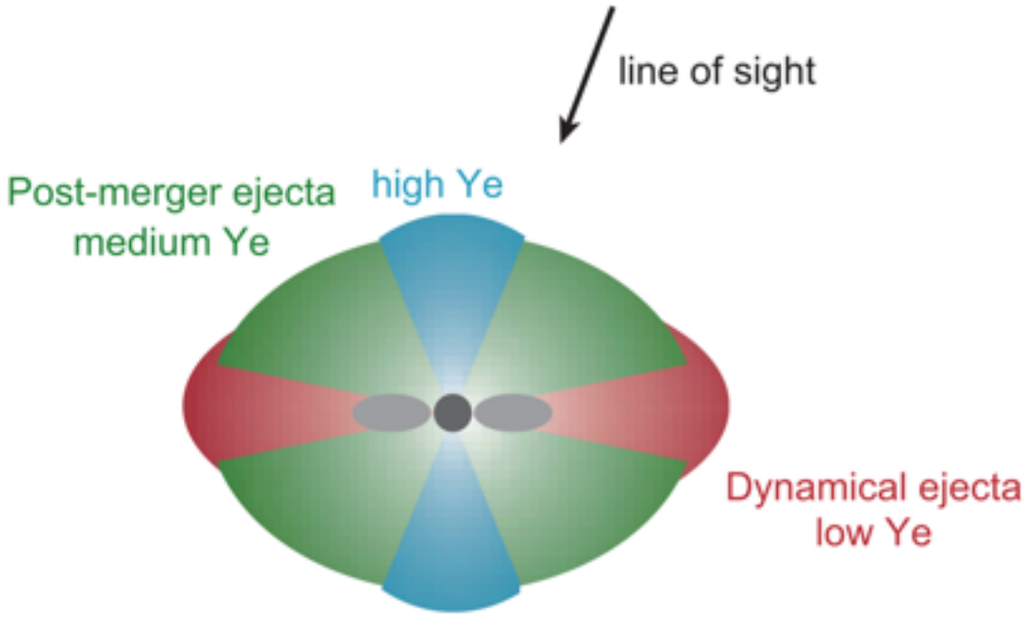
- **Gamma-ray**: Detect gamma-ray emission after 1.74 seconds of GW detection.
- **X-ray**: Detect after 9 days of GW detection.
- **Optical and NIR**: Identify optical counterpart after 10.87 hours.
- **Radio**: Detect after 16 days.

Abbott +2017

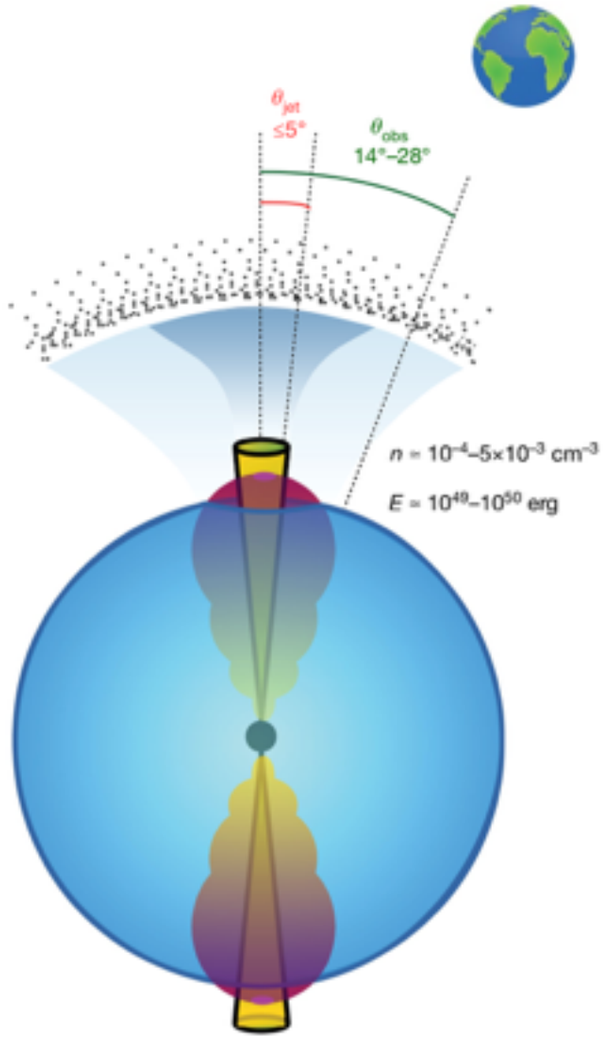


Implication from EM Observation

- Optical and infrared emissions are radiated by the radioactive decays of nuclei generated by r-process (Kilonova model).
- Radio, X-ray and gamma-ray emissions would come from the relativistic jet which was generated by the BNS merger.

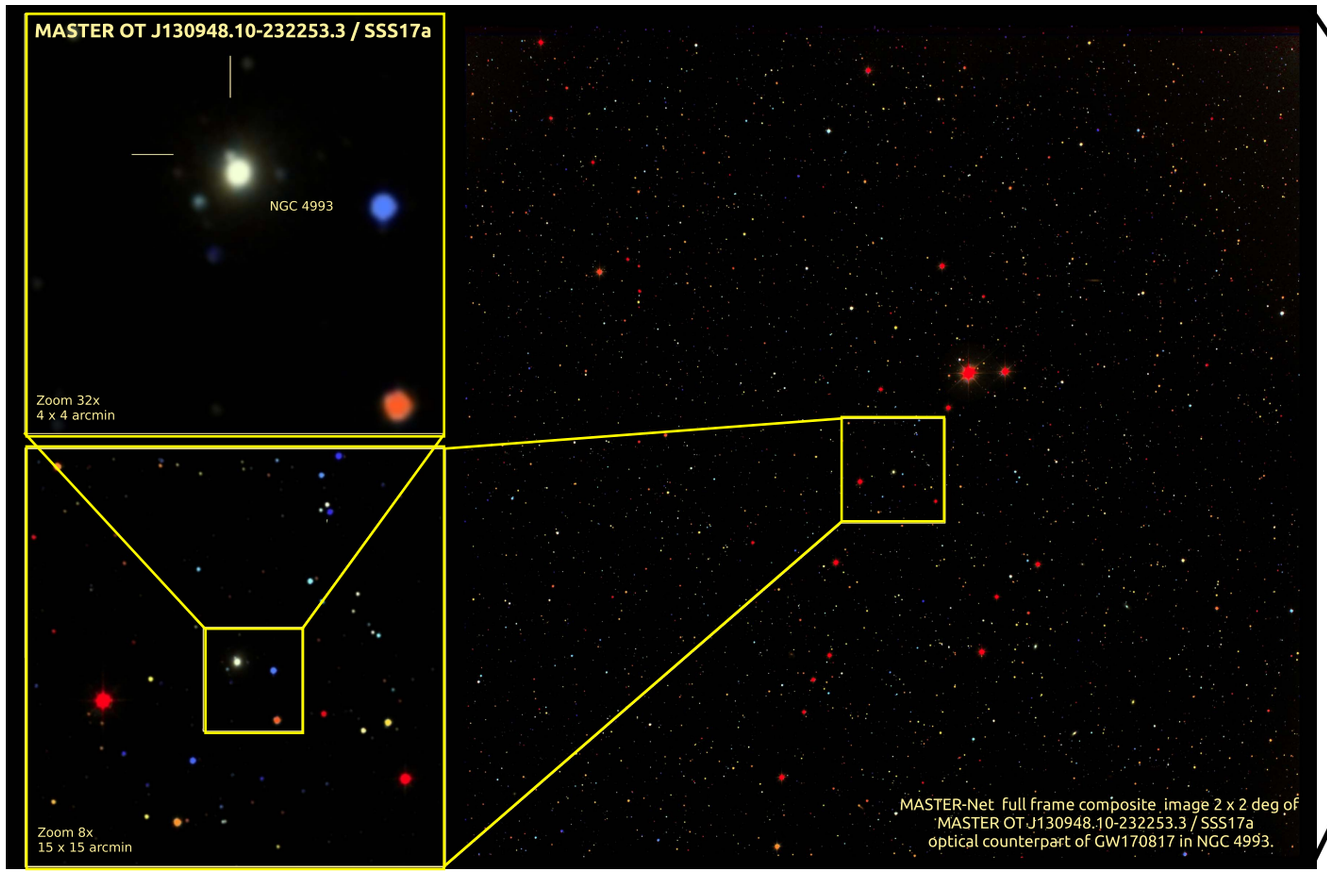


Tanaka+ 17

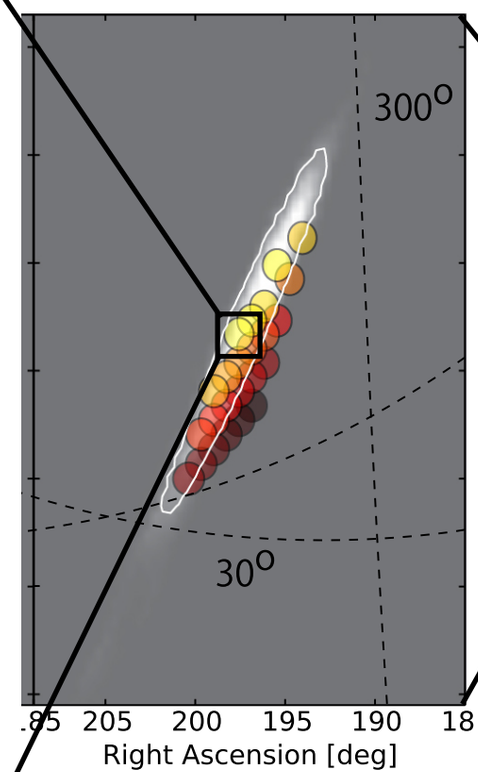


Mooley+ 18

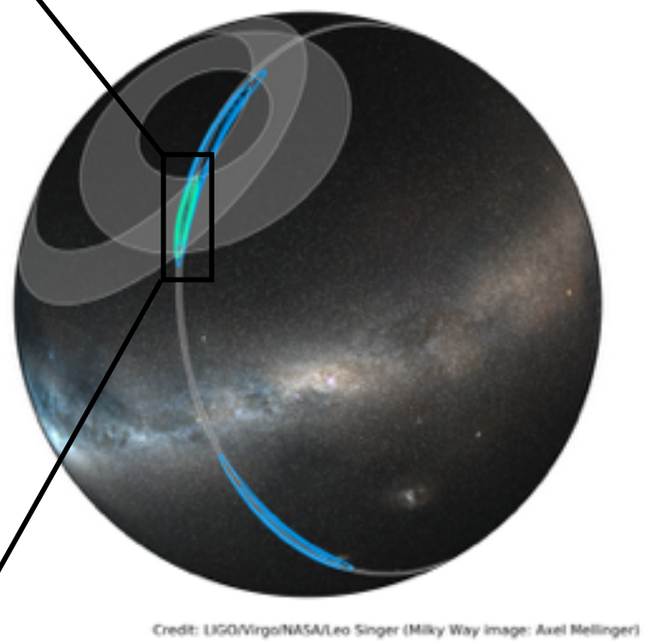
How to Identify Optical Counterpart



Lipunov+ 2017



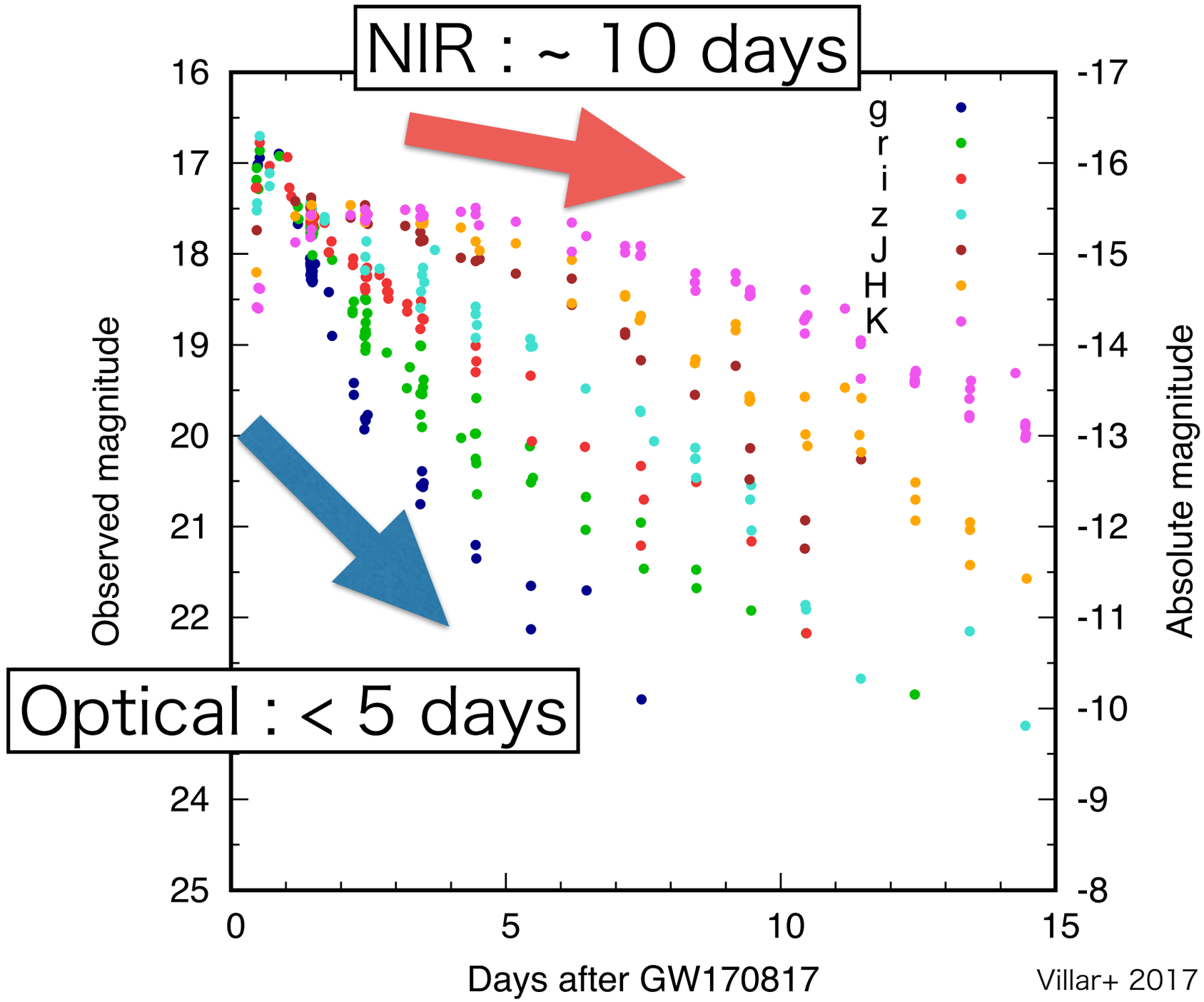
Area of GW170817



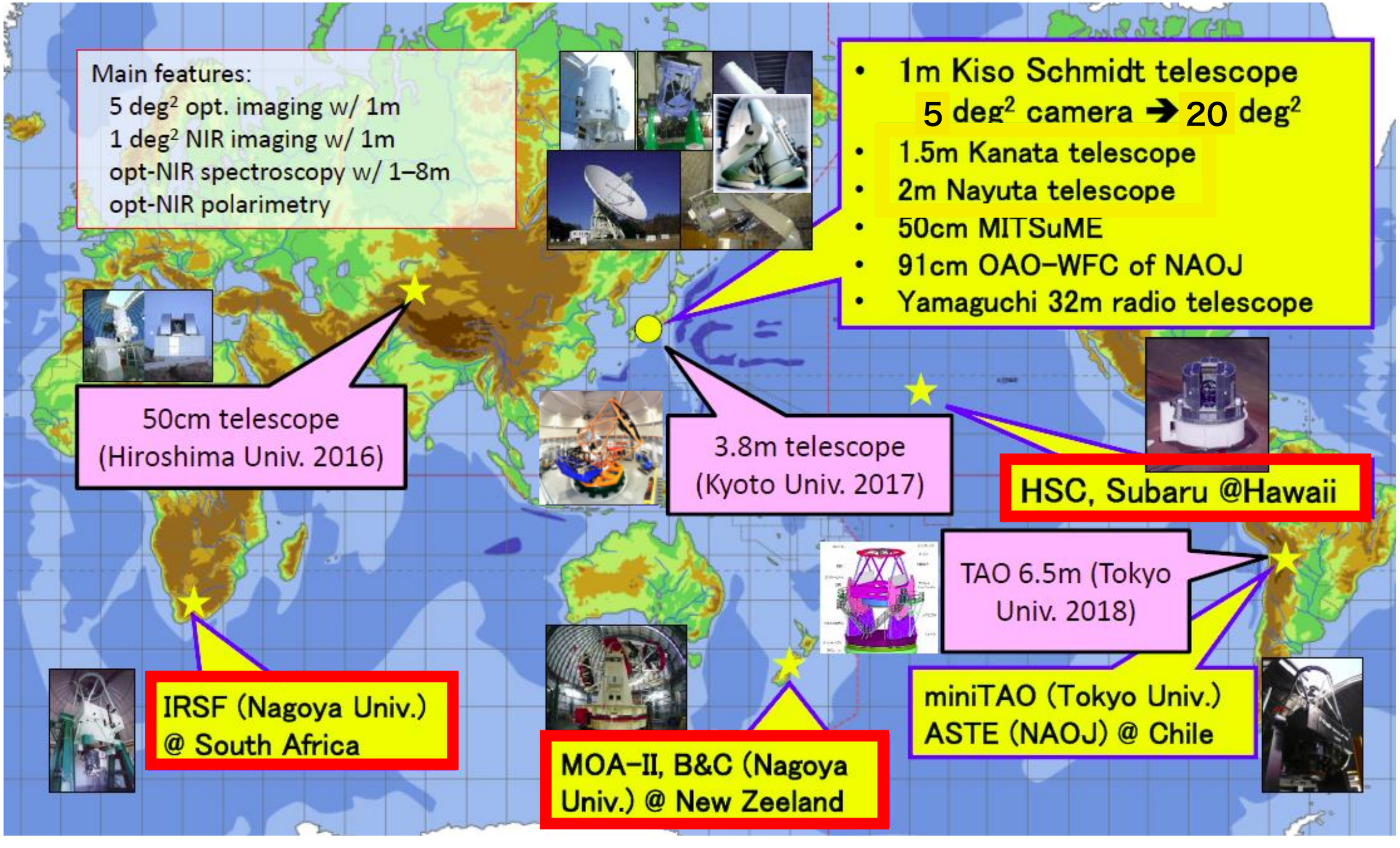
Tominaga+ 2018

- There are many stars and galaxies within the probable region of GW170817.
- It is not easy to identify an optical transient from the obtained image.

Decline of Optical and NIR Brightness



J-GEM (Japanese collaboration for Gravitational-wave Electro-Magnetic follow-up)



Purpose of J-GEM

Purpose

- Multi-messenger observation to reveal the physical background of GW sources
- Identify and observe an optical counterpart of GW source

Requirements

- Survey huge area (> 10 sq. degrees)
- Identify the optical counterpart as soon as possible to understand an early phase of GW event.

Approach

- We do a survey observation by using many Japanese telescopes

J-GEM Observation for GW170817

- J-GEM succeeded the observation for the EM counterpart of GW170817 by using IRSF, MOA-II, B&C and Subaru/HSC. (Utsumi+ 2017, Tanaka+ 2017, Tominaga+ 2018)

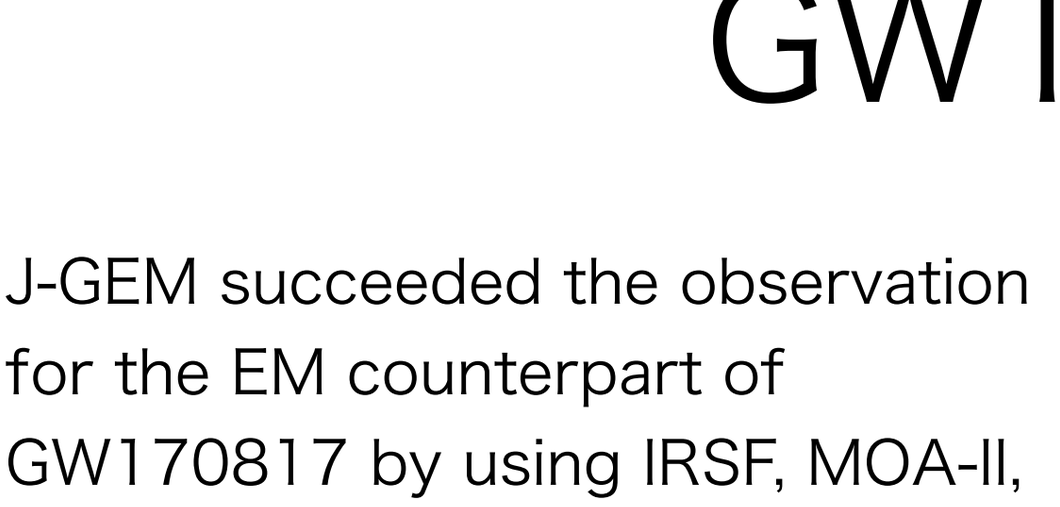
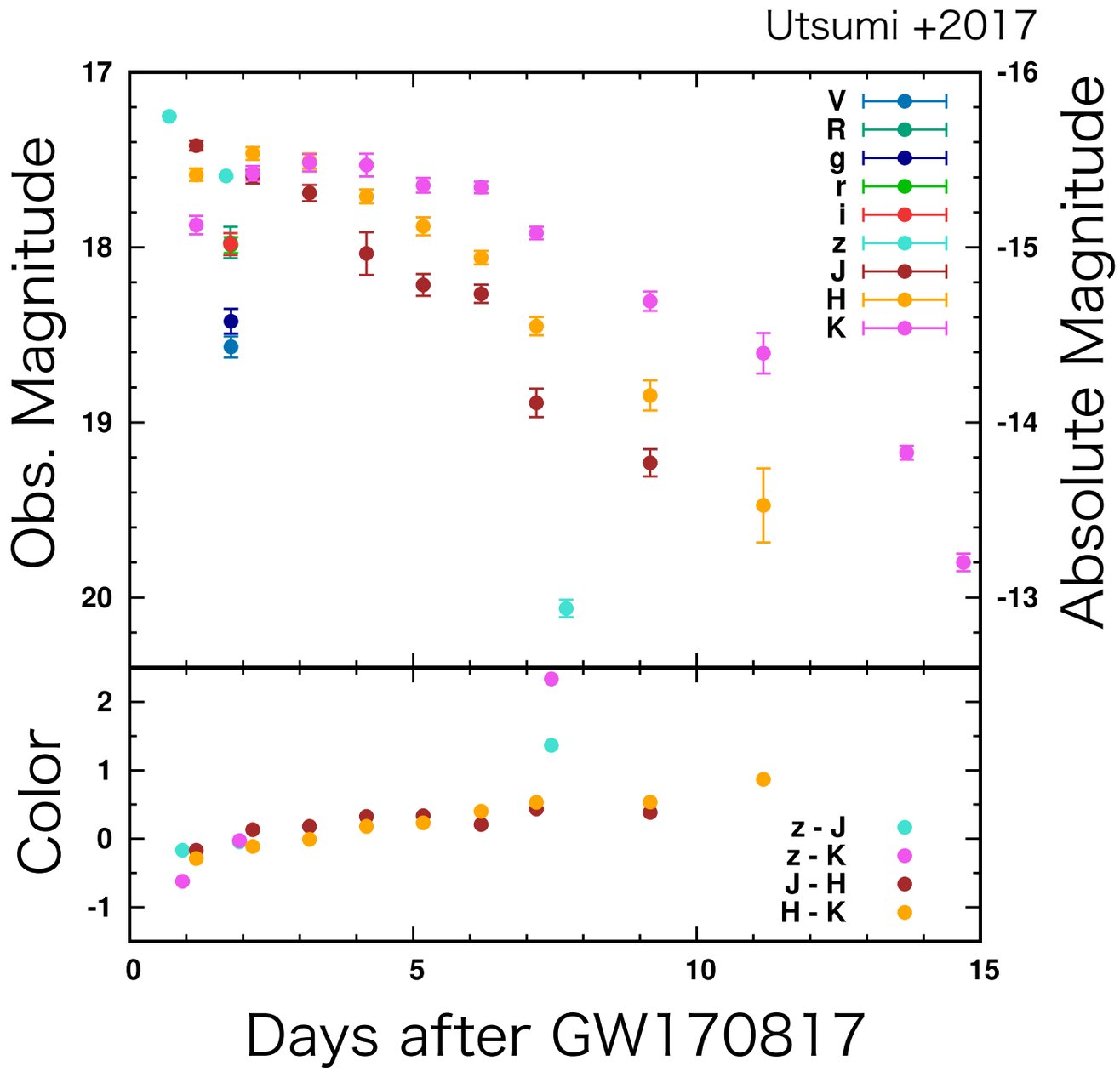


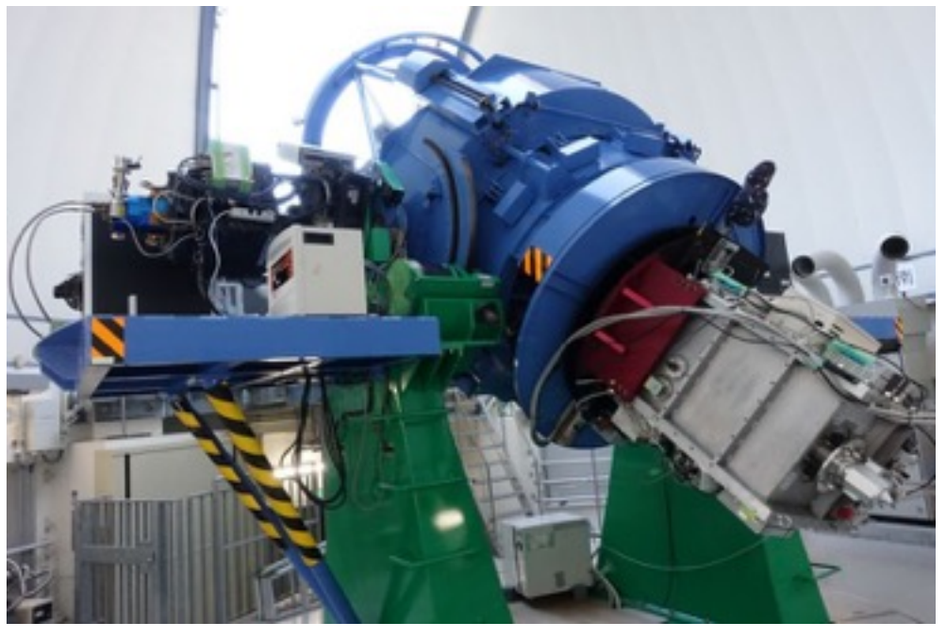
Image obtained by IRSF & Subaru/HSC



Strategy of J-GEM Observation

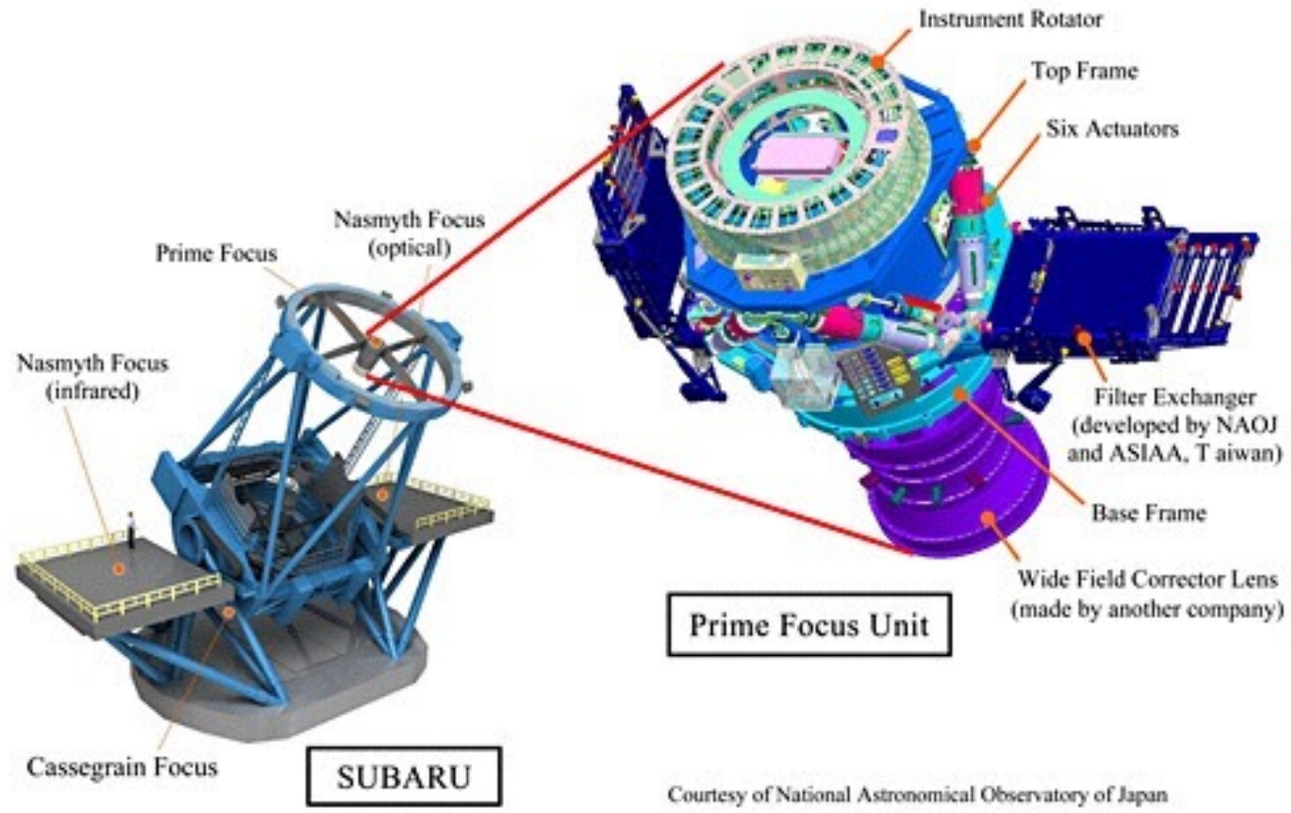
Two types of telescope

Normal Telescope (FoV < 1 deg^2)



- Kanata
- IRSF
- Nayuta
- OAO WFC
- MITSuME
- Akeno/Okayama
- B&C
- SaCRA

Telescope having large FoV (FoV > 1 deg^2)



Courtesy of National Astronomical Observatory of Japan

- Subaru
- Kiso Tomo-e
- MOA-II

- Different strategies depending on telescopes
- Identify the EM counterpart using both types of telescopes

Strategy for Normal Telescope

The survey area will be huge.

✦ Normal optical telescopes can not cover the entire survey area.

- Optical counterpart should be associated with a host galaxy.

  ➡ Observe candidate galaxies, and identify the associated transient **(Targeted Observation)**.

  GW170817 was discovered by the similar way.

- A huge possible region of the GW arrival direction

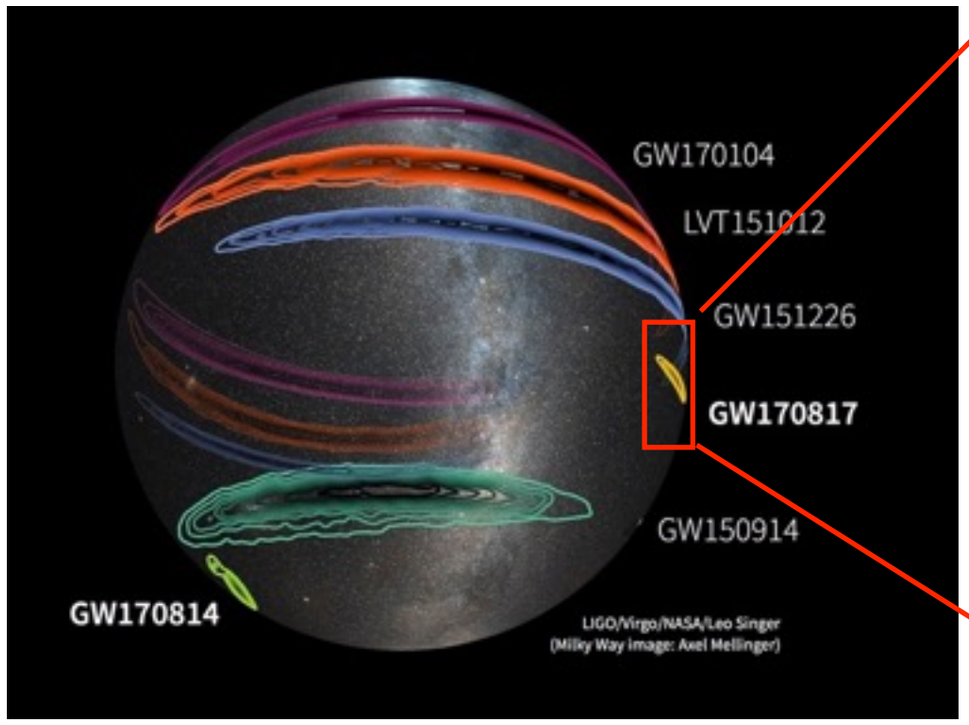
  ➡ List candidate galaxies within the possible region, and observe with many collaborate telescopes

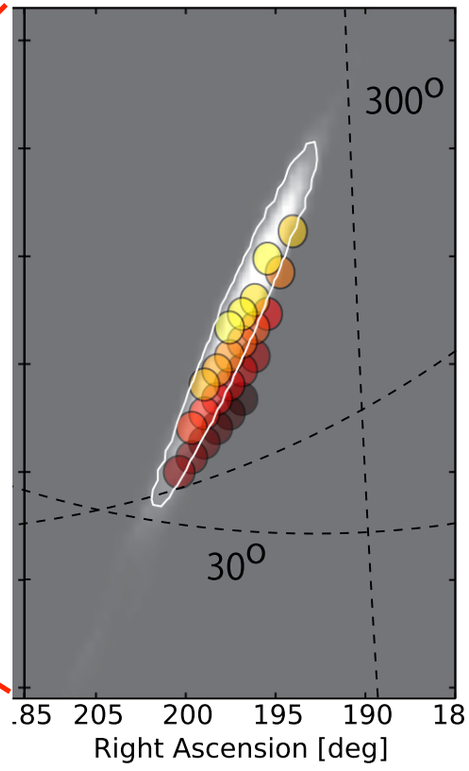
- Do not duplicate candidate host galaxy to survey efficiently.

  ➡ Share a list of candidate host galaxies, and realtime observing information

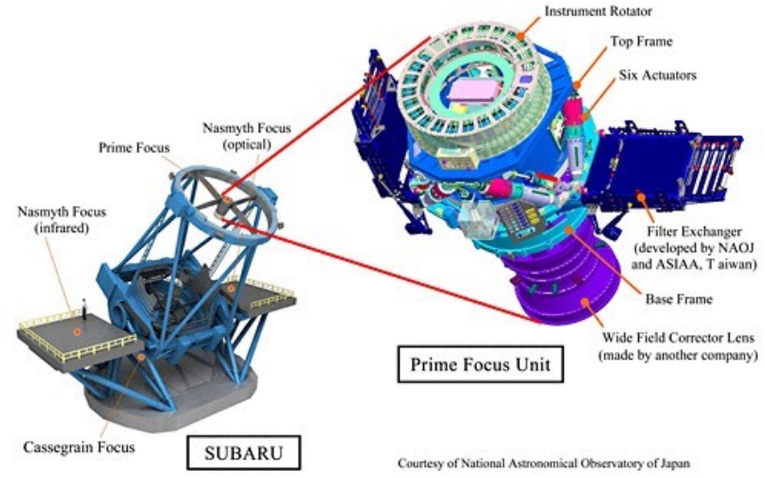
Strategy for Large-FoV Telescope

- We will survey an entire region of the GW possible area.





Tominaga+ 2018



- Subaru/HSC : 1.8 deg2, ~24.6 mag @60 s
- Kiso Tomo-e : 20 deg2, ~20.3 mag @180 s
- MOA-II : 2.2 deg2, ~18.2 mag @180 s

Morokuma+ 2016; Yoshida+ 2018

→ Share galaxy info

Scheme of Transient Exploration

①

J-GEM
Web System
planner

- Make galaxy list
- Serve realtime info

Scheme of Transient Exploration

LSC LIGO Scientific Collaboration

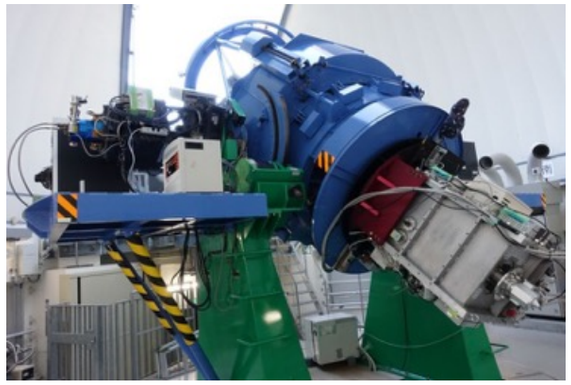
VIRGO

①

J-GEM

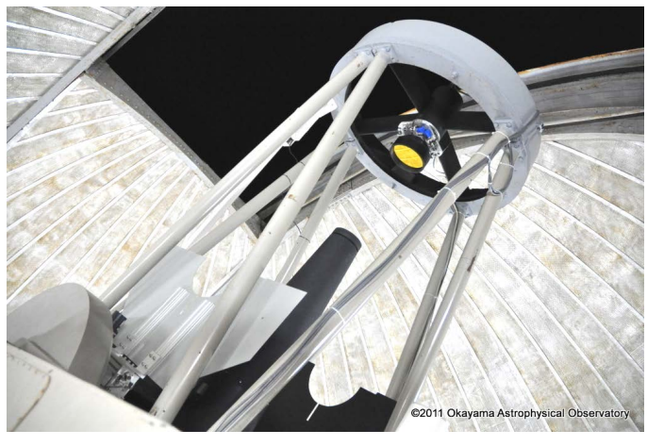
Web System

planner

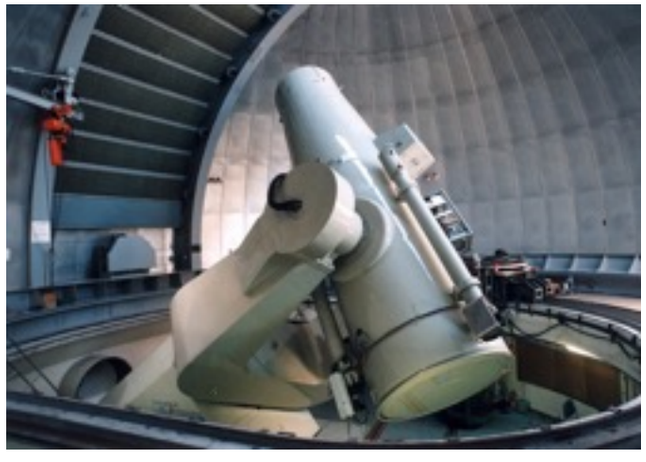


②

- Make galaxy list
- Serve realtime info



- Observe
- Reduce



Scheme of Transient Exploration

LSC LIGO Scientific Collaboration

VIRGO

①

J-GEM

Web System

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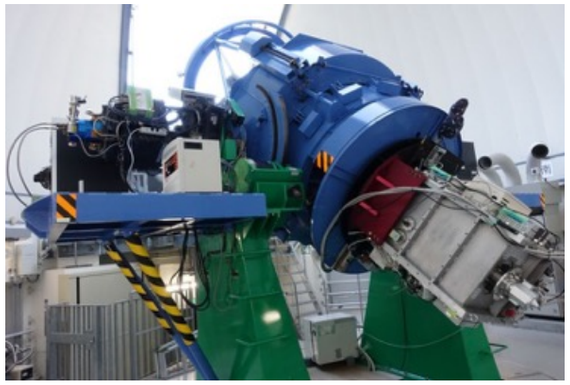
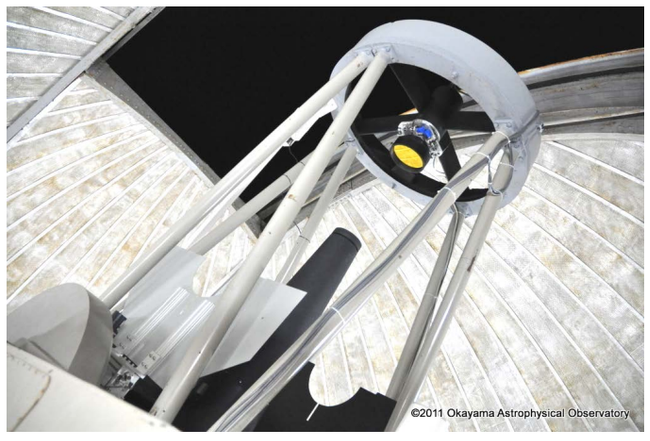


②

・Make galaxy list

・Serve realtime info

④



③

Image

Server

・Observe

・Reduce

・Save/show obtained images

・Calculate limiting flux

・Subtract image

Sharing Information System; planner

For engineering purpose

Event list | Candidates | Observing Log | Groups | Admin
Need machine readable format like JSON output? Just replace "main.html" with "processor.py" or click here.
Fri, 08 Feb 2019 13:14:24 GMT

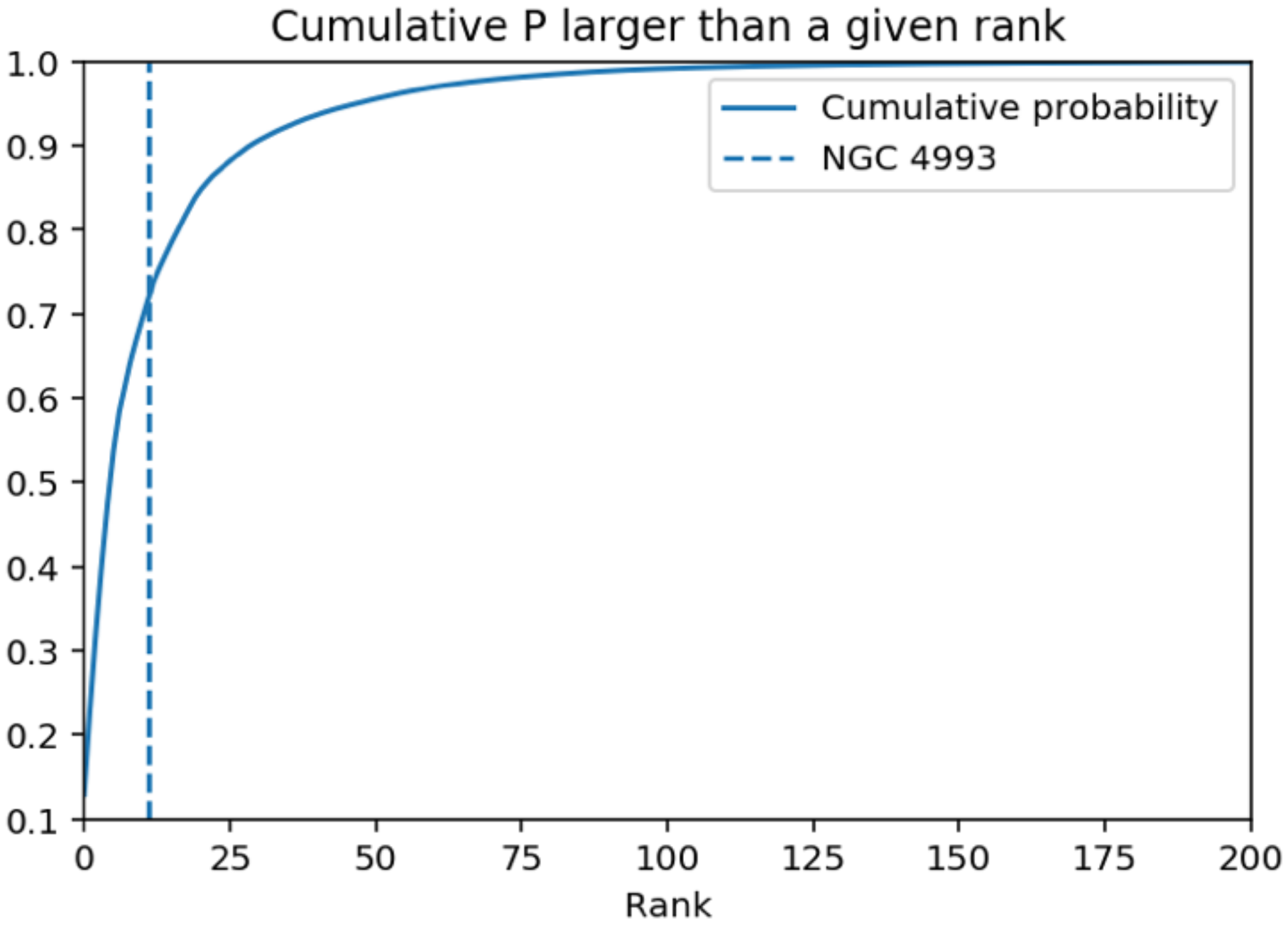
candidate : U181121

galid	eventid	prob	inserted	ra	dec	dist	OptExpected	NirExpected	state	obsids	updated	filter and depth (5 σ AB)	hastransient
GL232358+164636	U181121	0.13906	2018-11-21 03:42:01.651110	350.99	16.7766	184.1125	23.8	21.3	analyzed	OAOWFC, TIT-OAO-GRB50CM, MITSuME-Okayama, Kanata, MITSuME-Akeno, Kanata-HONIR	2018-11-27 12:00:02.091829	G=18.35, H=18.09, H=18.24, G=19.26, G=18.56, I=18.91, I=18.14, R=18.52, I=18.11, G=18.92, I=19.01, I=16.16, I=19.22, R=19.33, R=19.19, R=18.55, I=18.34, R=15.11, R=13.23, G=19.14, R=19.34, R=19.56, I=16.24, G=18.69, G=15.12, I=13.06, G=15.36, R=18.44, R=19.22, R=15.49	NO
GL232357+164638	U181121	0.13405	2018-11-21 03:42:01.651110	350.9892	16.7772	183.8161	23.8	21.3	analyzed	OAOWFC, TIT-OAO-GRB50CM, MITSuME-Okayama, Kanata, MITSuME-Akeno, Kanata-HONIR	2018-11-27 12:00:14.972767	G=18.35, H=18.09, H=18.24, G=19.26, G=18.56, I=18.91, I=18.14, R=18.52, I=18.11, G=18.92, I=19.01, I=16.16, I=19.22, R=19.33, R=19.19, R=18.55, I=18.34, R=15.11, R=13.23, G=19.14, R=19.34, R=19.56, I=16.24, G=18.69, G=15.12, I=13.06, G=15.36, R=18.44, R=19.22, R=15.49	NO
GL232431+165205	U181121	0.085688	2018-11-21 03:42:01.651110	351.1306	16.8681	179.6364	23.8	21.3	analyzed	Kanata, OAOWFC, TIT-OAO-GRB50CM, MITSuME-Akeno, Kanata-HONIR	2018-11-27 11:54:10.830935	R=15.11, G=15.12, R=19.84, R=19.56, I=16.16, R=18.55, G=15.36, I=19.22, G=19.26, H=18.31, I=16.24, H=16.52, G=18.69, R=19.02, R=15.49, I=18.34	NO
GL232301+174430	U181121	0.068632	2018-11-21 03:42:01.651110	350.7549	17.7417	179.6273	23.8	21.3	observed	Kanata, SaCRA-MuSaSHI, SaCRA, Kanata-HONIR	2018-11-29 03:15:30.256661	z=18.62, r=18.68, z=18.98, z=18.99, i=19.01, r=18.62, i=19.03, z=18.68, r=18.66, r=18.99, R=19.20, i=18.66, i=18.98, H=18.44, R=19.15, i=18.68, i=18.69	NO

Galaxy ID | Probability | Galaxy Info | Obs Teles | Obs Info | Flag

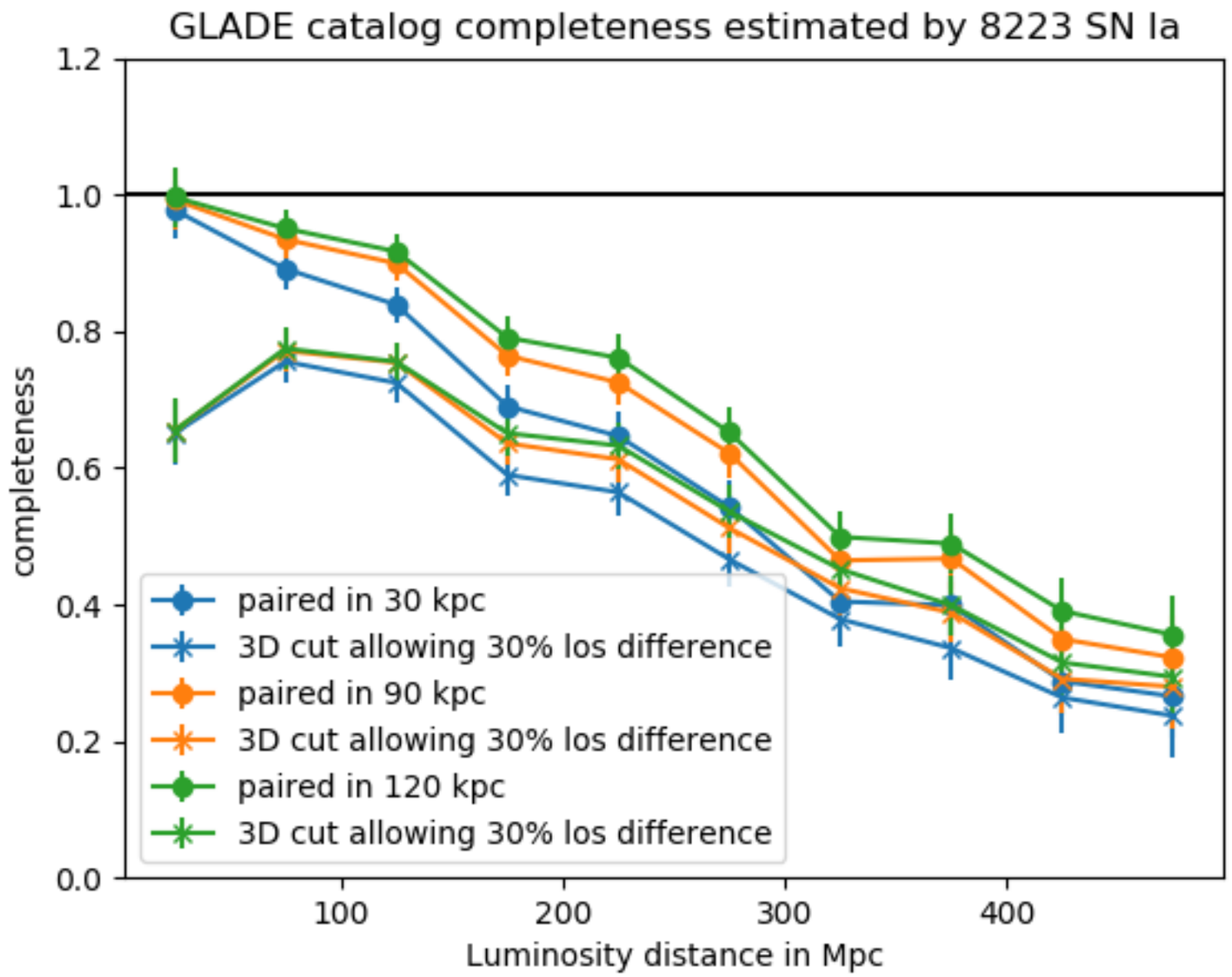
- List candidate galaxies from GLADE catalogue including over 3 million galaxies.
- Share information to avoid a duplication of observations

J-GEM Ranking on GW170817



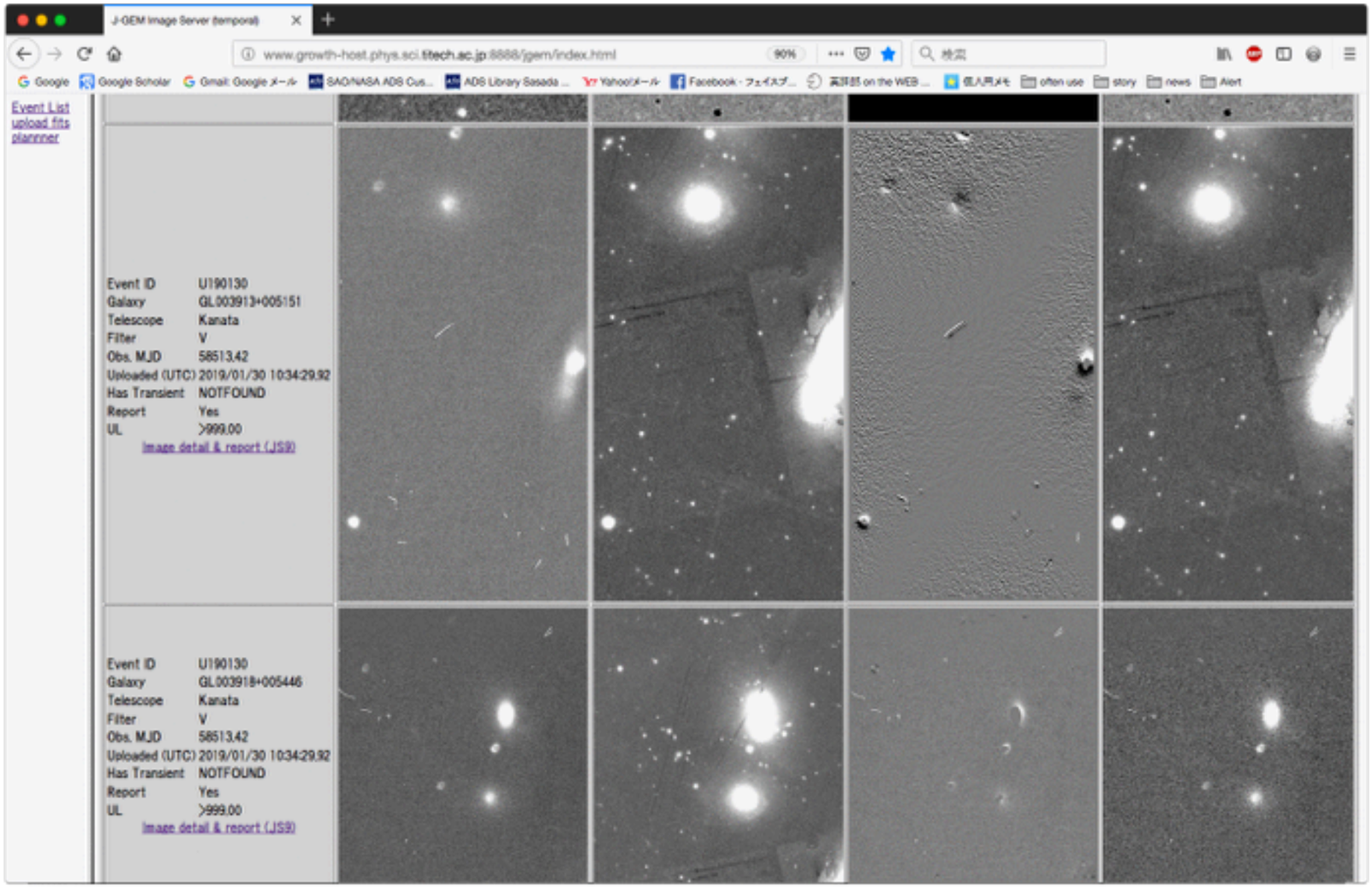
- NGC 4993 got 11-th rank based on GLADE galaxies with 3D probability map and B-mag brightness.

How complete?



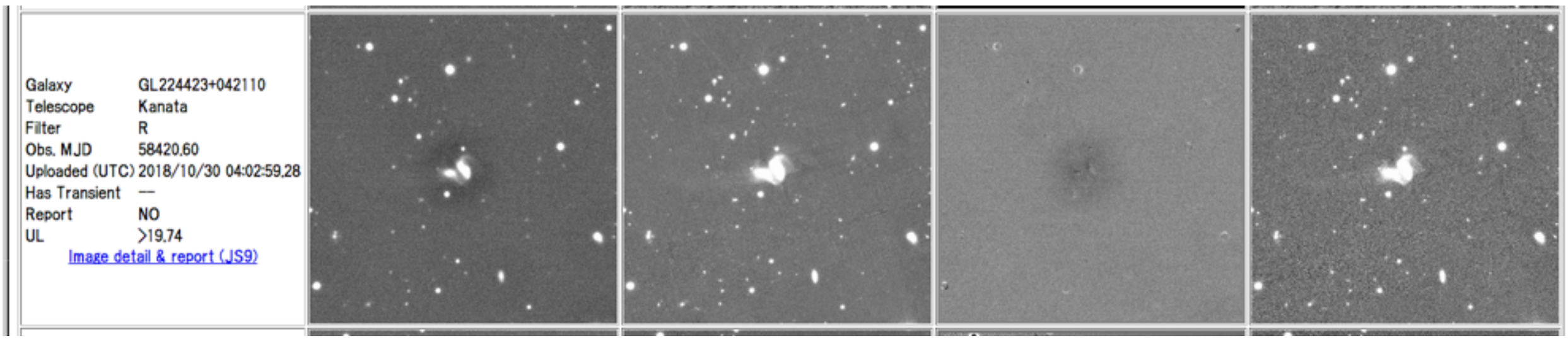
- 8223 SN Ia are used to validate GLADE completeness
- Targeted observation with planner is promising for GW events up to 200Mpc

Image Subtraction



- Web-base image server system.
- Assemble images obtained by each telescope.

Identification



- Compare with reference image obtained by several projects including PanSTARRS and 2MASS.
- Do image subtraction
- Compare between obtained and reference images using subtracted image and blinking gif image.

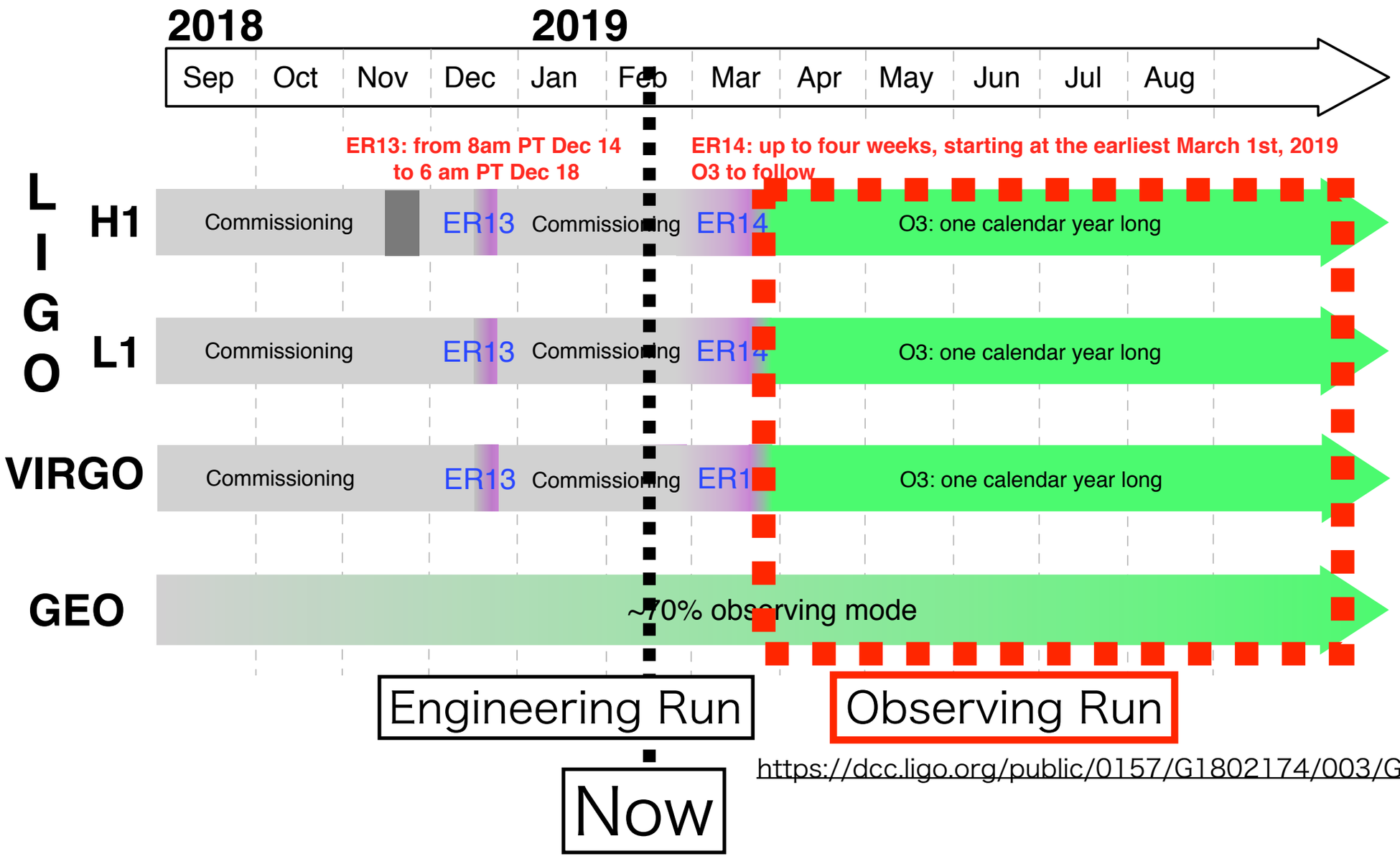
Schedule for O3

LIGO-VIRGO Joint Run Planning Committee

LIGO-G1801056

Working schedule for O3

(Public document G1801056-v4, based on G1800889-v7)



https://dcc.ligo.org/public/0157/G1802174/003/G1802174-v3.pdf

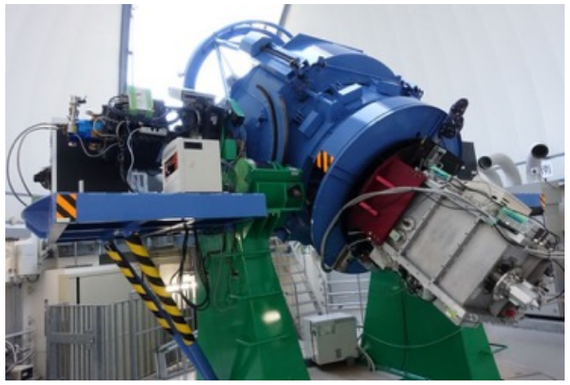
We have done three-times test observations for GW alert.

Coordinated Observation for GW Alert

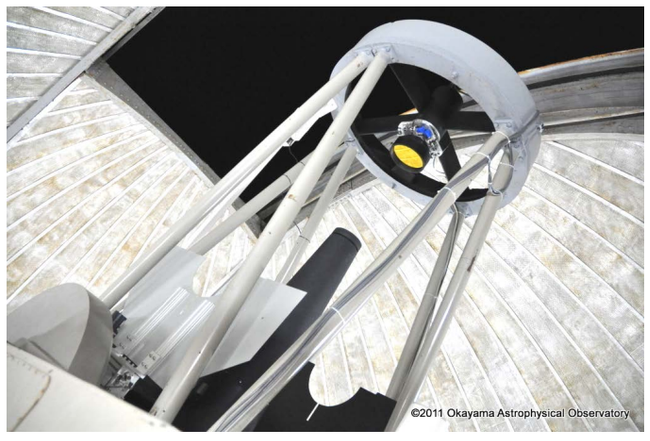
Dummy Alert

Including supernova as transient

J-GEM
Web System
playground



・Organize obs info and transient info



・Observe
・Send reduced images

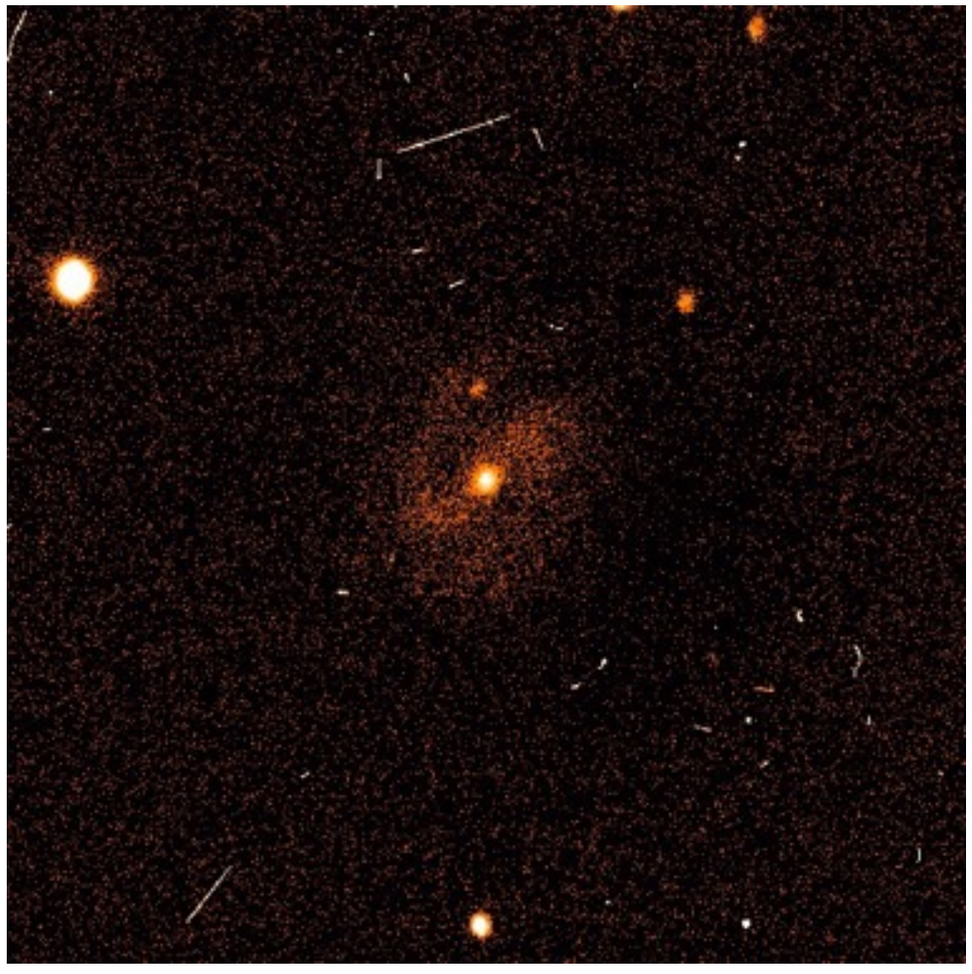
Image
Server

・Assemble images
・Find transient by eye

Coordinated Observation

Observed 10/33 galaxies using two telescopes in three hours.

Obtained Image

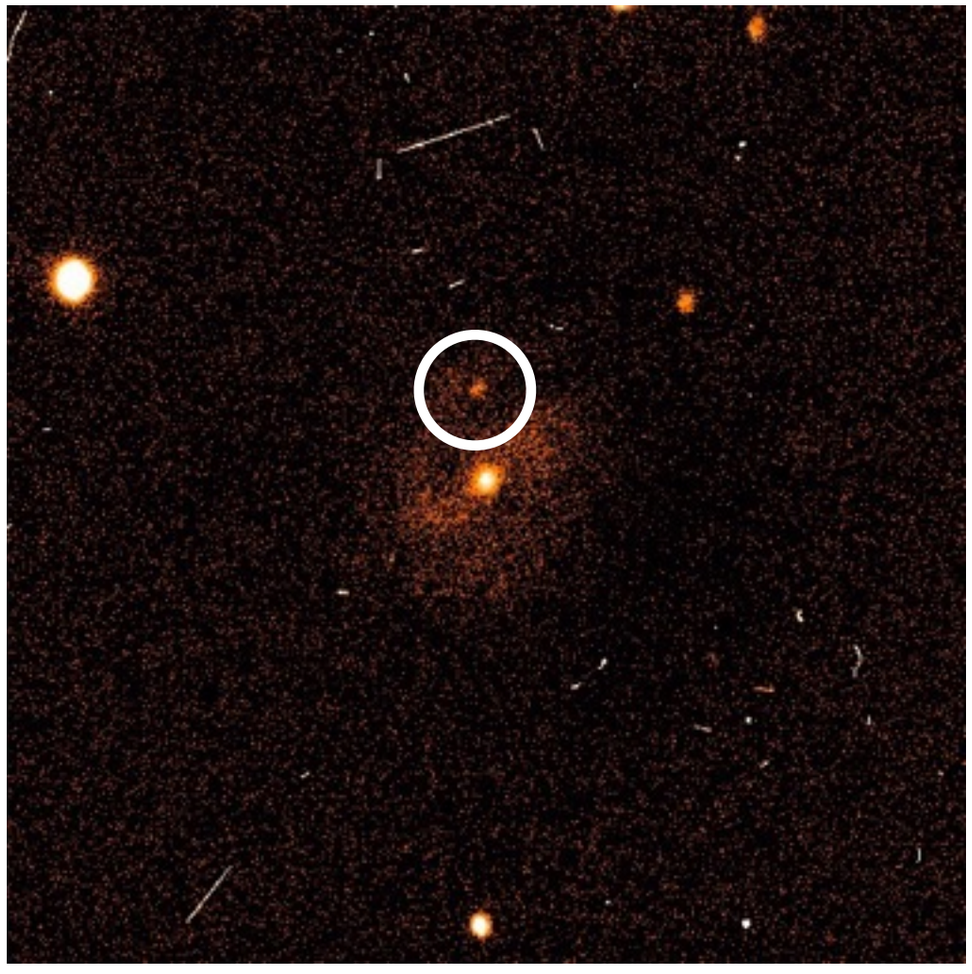


Reference Image

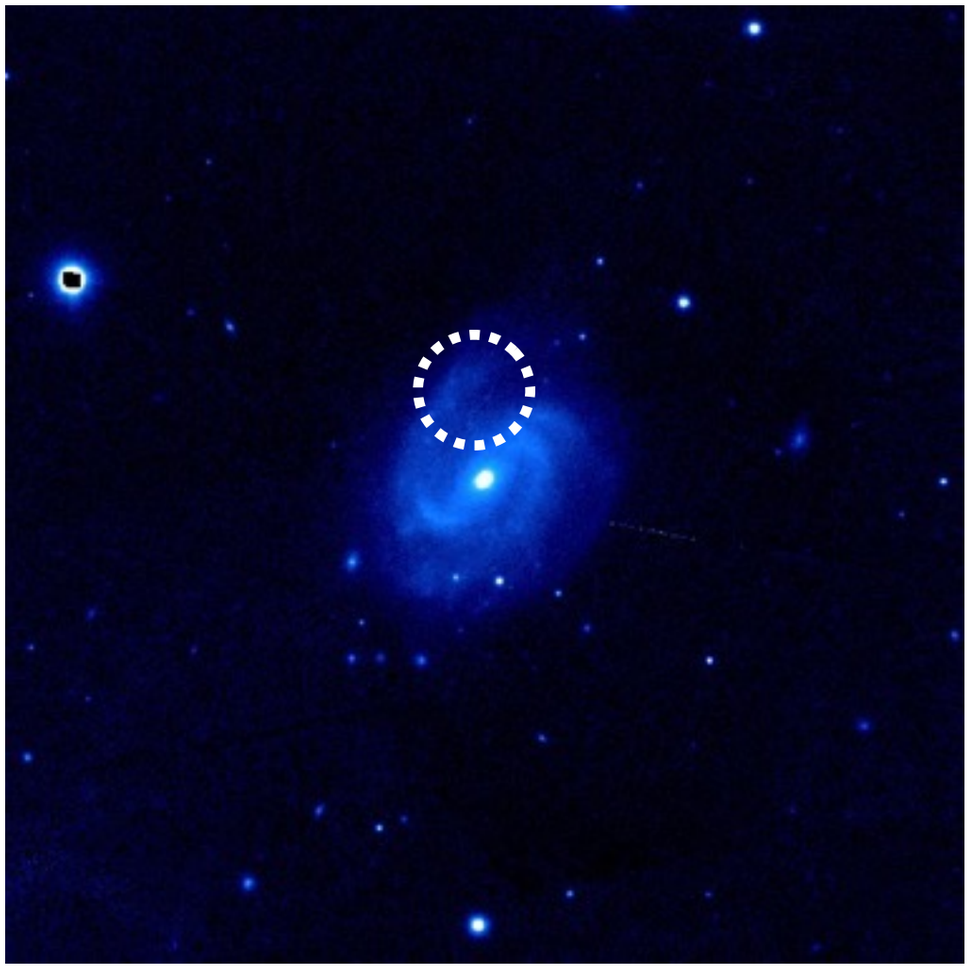
Coordinated Observation

Observed 10/33 galaxies using two telescopes in three hours.

Obtained Image



Reference Image



We have identified the transient (supernova, ~18.8 mag)
1.5 hours after starting observations.

Engineering Run (ER13)

- Engineering Run (ER13) was conducted from 14th to 18th Dec.
- We did the preparation of EM observation for GW event.

There was no public alert of GW event during ER13.

Summary

- J-GEM succeeded to observe an EM counterpart of GW170817.
- Construct observational systems both for normal and wide-field FoV telescopes to observe an optical counterpart of GW source.
- Made web-base systems:
  1. Share a list of candidate galaxies in a probability area of GW event and observational information.
  2. Assemble observed images and subtract from reference to identify the transient.
- Did coordinated test observations with dummy alert of GW event.

We prepare a system to identify EM counterpart.

Thank you for your attention